<u>ODD BOUNCE IMAGE ROTATION SYSTEM IN ELLIPSOMETER SYSTEMS</u>

This Application is a Continuation-In-Part of Provisional Application Serial No. 60/281,706, filed 04/06/01.

TECHNICAL FIELD

The present invention relates to polarization state modifying systems which find application in ellipsometer, polarimeter and the like systems. More particularly the present invention comprises an image rotating system comprised of a sequence of an odd number of reflecting elements, such that a linearly, or partially linearly polarized electromagnetic beam caused to enter, reflectively interacts with the odd number of reflecting elements and exits in a direction which is essentially non-deviated and non-displaced, with an azimuthally rotated, but otherwise substantially unchanged, polarization state.

BACKGROUND

The practice of ellipsometry is well established as a non-destructive approach to determining characteristics of sample systems, and can be practiced in real time. The topic is well described in a number of publications, one such publication being a review paper by Collins, titled "Automatic Rotating Element Ellipsometers: Calibration, Operation and Real-Time Applications", Rev. Sci. Instrum., 61(8) (1990).

Before proceeding, as it is relevant to the present

invention, it is noted that ellipsometer systems generally comprise means for setting a linear or elliptical polarization state, (typically substantially linear).

5   Continuing, in general, modern practice of ellipsometry typically involves causing a spectroscopic beam of electromagnetic radiation, in a known state of polarization, to interact with a sample system at at least one angle of incidence with respect to a normal to a surface thereof, in a plane of

10   incidence. (Note, a plane of incidence contains both a normal to a surface of an investigated sample system and the locus of said beam of electromagnetic radiation). Changes in the polarization state of said beam of electromagnetic radiation which occur as a result of said interaction with said sample system are indicative

15   of the structure and composition of said sample system. The practice of ellipsometry further involves proposing a mathematical model of the ellipsometer system and the sample system investigated by use thereof, and experimental data is then obtained by application of the ellipsometer system. This is

20   typically followed by application of a square error reducing mathematical regression to the end that parameters in the mathematical model which characterize the sample system are evaluated, such that the obtained experimental data, and values calculated by use of the mathematical model, are essentially the

25   same.

       A typical goal in ellipsometry is to obtain, for each wavelength in, and angle of incidence of said beam of electromagnetic radiation caused to interact with a sample

30   system, sample system characterizing PSI and DELTA values, (where PSI is related to a change in a ratio of magnitudes of orthogonal components r_p/r_s in said beam of electromagnetic radiation, and wherein DELTA is related to a phase shift entered between said

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orthogonal components r_p and r_s), caused by interaction with said sample system:

$$PSI = \left| r_p / r_s \right|; \text{ and}$$

$$DELTA = (\Delta r_p - \Delta r_s).$$

As alluded to, the practice of ellipsometry requires that a mathematical model be derived and provided for a sample system and for the ellipsometer system being applied. In that light it must be appreciated that an ellipsometer system which is applied to investigate a sample system is, generally, sequentially comprised of:

a. a Source of a beam electromagnetic radiation;

b. a Polarizer element;

c. optionally a compensator element;

d. (additional element(s));

e. a sample system;

f. (additional element(s));

g. optionally a compensator element;

h. an Analyzer element; and

i. a Spectroscopic Detector System.

Each of said components b. - i. must be accurately represented by a mathematical model of the ellipsometer system along with a vector which represents a beam of electromagnetic radiation

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provided from said source of a beam electromagnetic radiation,
Identified in a. above)

Various conventional ellipsometer configurations provide
that a Polarizer, Analyzer and/or Compensator(s) can be rotated
during data acquisition, and are describe variously as Rotating
Polarizer (RPE), Rotating Analyzer (RAE) and Rotating Compensator
(RCE) Ellipsometer Systems. It is noted, that nulling
ellipsometers also exist in which elements therein are rotatable
in use, rather than rotating. Generally, use of a nulling
ellipsometer system involves imposing a substantially linear
polarization state on a beam of electromagnetic radiation with a
linear polarizer, causing the resulting polarized beam of
electromagnetic radiation to interact with a sample system, and
then adjusting an analyzer to an azimuthal azimuthal angle which
effectively cancels out the beam of electromagnetic radiation
which proceeds past the sample system. The azimuthal angle of
the analyzer at which nulling occurs provides insight to
properties of the sample system.

Continuing, in use, data sets can be obtained with an
ellipsometer system configured with a sample system present,
sequentially for cases where other sample systems are present,
and where an ellipsometer system is configured in a straight-
through configuration wherein a beam of electromagnetic radiation
is caused to pass straight through the ellipsometer system
without interacting with a sample system. Simultaneous
mathematical regression utilizing multiple data sets can allow
calibration of ellipsometers and evaluation of sample system
characterizing PSI and DELTA values over a range of wavelengths.
The obtaining of numerous data sets with an ellipsometer system
configured with, for instance, a sequence of sample systems
present and/or wherein a sequential plurality of polarization
states are imposed on an electromagnetic beam caused to interact
therewith, can allow system calibration of numerous ellipsometer

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system variables.

Patent to Herzinger, No. 6,137,618 is disclosed as it describes a Single Brewster Angle Polarizer in the context of multiple reflecting means, and discloses prior art dual Brewster Angle Single Reflective Means Polarizer Systems.

Another Patent, to Herzinger et al., No. 6,084,675 describes an adjustable beam alignment compensator/retarder with application to spectroscopic ellipsometry.

Patent No. 6,118,537 to Johs et al. describes a multiple Berek plate optical retarder system.

Patent No. 6,141,102 to Johs et al. describes a single triangular shaped optical retarder element.

Patent No. 5,946,098 to Johs et al., describes dual tipped wire grid polarizers in combination with various compensator/retarder systems.

Patent No. 6,100,981 to Johs et al., describes a dual horizontally oriented triangular shaped optical retarder.

Patent No. 6,084,674 to Johs et al., describes a parallelogram shaped optical retarder element.

Patent No. 5,963,325 to Johs et al., describes a dual vertically oriented triangular shaped optical retarder element.

A Patent to Johs et al., No. 5,872,630 is disclosed as it describes an ellipsometer system in which an analyzer and polarizer are maintained in a fixed in position during data acquisition, while a compensator is caused to continuously rotate.

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A Patent to Thompson et al. No. 5,706,212 is also disclosed
as it teaches a mathematical regression based double Fourier
series ellipsometer calibration procedure for application,
primarily, in calibrating ellipsometers system utilized in
infrared wavelength range. Bi-refringent, transmissive
window-like compensators are described as present in the system
thereof, and discussion of correlation of retardations entered by
sequentially adjacent elements which do not rotate with respect
to one another during data acquisition is described therein.

Further Patents of which the Inventor is aware include:

Nos. 5,757,494; and
5,956,145;

to Green et al., in which are taught a method for extending the
range of Rotating Analyzer/Polarizer ellipsometer systems to
allow measurement of DELTA'S near zero (0.0) and one-hundred-
eighty (180) degrees, and the extension of modulator element
ellipsometers to PSI'S of forty-five (45) degrees. Said Patents
describes the presence of a variable, transmissive, bi-refringent
component which is added, and the application thereof during data
acquisition to enable the identified capability.

A Patent to He et al., No. 5,963,327 is disclosed as it
describes an ellipsometer system which enables providing a
polarized beam of electromagnetic radiation at an oblique
angle-of-incidence to a sample system in a small spot area.

Patents of general interest of which the Inventor is aware
include:

Patent to Woollam et al, No. 5,373,359;
Patent to Johs et al. No. 5,666,201;

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Patent to Green et al., No. 5,521,706; and

Patent to Johs et al., No. 5,504,582;

and are disclosed as they pertain to ellipsometer systems.

A Patent to Coates et al., No. 4,826,321 is disclosed as it describes applying a reflected monochromatic beam of plane polarized electromagnetic radiation at a Brewster angle of incidence to a sample substrate to determine the thickness of a thin film thereupon. This Patent also describes calibration utilizing two sample substrates, which have different depths of surface coating.

Other Patents which describe use of reflected electromagnetic radiation to investigate sample systems are:

Nos. RE 34,783,
    4,373,817,
    5,045,704

to Coates; and

    5,452,091

to Johnson.

A Patent to Bjork et al., No. 4,647,207 is disclosed as it describes an ellipsometer system which has provision for sequentially, individually positioning a plurality of reflective polarization state modifiers in a beam of electromagnetic radiation. Patent Nos. 4,210,401; 4,332,476 and 4,355,903 are also identified as being cited in the 207 Patent. It is noted that systems as disclosed in these Patents, (particularly in the 476 Patent), which utilize reflection from an element to modify a polarization state can, if such an element is an essential duplicate of an investigated sample and is rotated ninety degrees

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therefrom, the effect of the polarization state modifying element on the electromagnetic beam effect is extinguished by the sample.

A Patent to Mansuripur et al., No. 4,838,695 is disclosed as it describes an apparatus for measuring reflectivity.

Patents to Rosencwaig et al., Nos. 4,750,822 and 5,595,406 are also identified as they describe systems which impinge electromagnetic beams onto sample systems at oblique angles of incidence. The 406 Patent provides for use of multiple wavelengths and multiple angles of incidence. For similar reasons Patent No. 5,042,951 to Gold et al. is also disclosed.

In addition to the identified Patents, certain Scientific papers are also identified.

A paper by Johs, titled "Regression Calibration Method for Rotating Element Ellipsometers", Thin Solid Films, 234 (1993) is also disclosed as it describes a mathematical regression based approach to calibrating ellipsometer systems.

A paper by Smith, titled "An Automated Scanning Ellipsometer", Surface Science, Vol. 56, No. 1. (1976), is also mentioned as it describes an ellipsometer system which does not require any moving, (eg. rotating), elements during data acquisition.

Even in view of relevant prior art, there remains need for a more convenient approach to providing linearly polarized beams of electromagnetic radiation in which the azimuthal angle of the linear polarization can be controlled. The present invention responds to said identified needs.

DISCLOSURE OF THE INVENTION

The present invention comprises an "odd bounce optical image rotating system", and method of its application in ellipsometer and polarimeter and the like systems. The odd bounce optical image rotating system serves to rotate the azimuthal angle of a linearly, or partially linearly polarized beam of electromagnetic radiation without entering significant deviation or displacement of the propagation direction locus thereof, or significantly altering the polarization state thereof, (ie. it does not cause significant shifting of energy from a major intensity orthogonal component into the other orthogonal component, or the shifting of phase angle therebetween). The odd bounce optical image rotating system can be described as a sequence of an odd number of reflective elements oriented in a manner which causes an entering beam of electromagnetic radiation to reflect from a first thereof onto the second thereof and from the second thereof onto the third thereof etc. For a three (3) reflective element odd bounce optical image rotating element system, said three reflections cause a beam of electromagnetic radiation to emerge from the third reflective element with a rotated linear or partially linear polarization azimuthal angle and in a direction which is not significantly deviated or displaced from the locus of the input beam, even when the odd bounce optical image rotating system is caused to stepwise or continuously rotate about an axis coincident with the locus of the beam of electromagnetic radiation. The same is generally true for an odd bounce optical image rotating element system comprising any odd number, (eg. 3, 5, 7 etc.) of reflective elements. It is noted that the greater the number of reflective elements the more normal the angle of incidence a beam can make thereto, and higher angles of incidence cause less aberration effects. Also, where more than three reflection elements are present certain

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non-idealities caused by the reflection elements can be canceled by utilizing non-coincident coordinate systems for said reflections.   A trade-off, however, is that the greater the number of reflective elements present, the more difficult it is to align the system to avoid said beam deviation and displacement.

Coupling the odd bounce optical image rotating system with a substantially linear polarizing polarizer provides a polarizer system in which the substantially linear polarizing polarizer can remain stationary while the azimuthal angle of a substantially linearly polarized beam of electromagnetism exiting therefrom, (as viewed from a position along the locus of an electromagnetic beam caused to enter thereto), is rotated.

For general insight, it is also noted that a single three-hundred-sixty (360) degree rotation of a present invention odd bounce optical image rotating element system about an axis coincident with a beam of electromagnetic radiation which functionally passes therethrough, causes seven-hundred-twenty (720) degrees of rotation of the major intensity orthogonal component. This is not of any critical consequence, but is mentioned as it must be taken into account during practice of present invention methodology.

In the context of a material system investigation system, (eg. ellipsometer, polarimeter etc.), sequentially comprising:

source of electromagnetic radiation;

substantially linear polarizer;

stage for supporting a sample system

analyzer; and

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detector;

the present invention teaches the presence of at least one odd
bounce optical image rotating system being present between said
substantially linear polarizer and said stage for supporting a
sample system and/or between said stage for supporting a sample
system and said analyzer, said at least one odd bounce optical
image rotating system comprising an odd number of at least three
reflective elements; such that a beam of electromagnetic
radiation provided by said source of electromagnetic radiation,
after passing through said substantially linear polarizer,
interacts with a sample system place on the stage for supporting
a sample system passes through said analyzer before entering said
detector, said beam of electromagnetic radiation further
interacting with each of said odd number of reflective elements
of said at least one odd bounce optical image rotating element,
and exiting therefrom along a substantially non-deviated
non-displaced trajectory.

Again, the odd bounce optical image rotating system can
consist of any odd number of reflective elements, with three (3)
and five (5) being preferred in the practical sense.

The present invention also includes a method of obtaining
data, comprising the steps of:

a. providing a system which comprises an odd bounce optical
image rotating system, as described above;

b. causing a beam of electromagnetic radiation to exit said
source of electromagnetic radiation, interact with said
substantially linear polarizer, a sample system and said analyzer
prior to entering said detector, and in addition interact with
said at least one odd bounce optical image rotating element

without significant change in trajectory;

c. collecting output signals from said detector.

An additional step can further comprise the step of causing
the at least one odd bounce optical image rotating element to
rotate, step-wise or continuously, around the locus of the
trajectory of the electromagnetic beam while practicing step c.
Note, where the rotation is step-wise, motion is stopped during
data acquisition.

In addition, said material system investigation system, (eg.
ellipsometer, polarimeter etc.), can be caused to include a
rotating compensator which during use in collecting data is
caused to continuously rotate about a locus of an electromagnetic
beam passing therethrough, while the substantially linear
polarizer and analyzer are held essentially fixed in position and
the present invention odd bounce optical image rotating element
is caused to be stepped through a series of rotation positions
around the locus of the beam of electromagnetic radiation caused
to pass therethrough, (and held motionless during data
acquisition).   This allows collecting data at multiple
substantially linear polarization state azimuthal angle
orientations, much as is typically effected by stepwise rotating
a linear polarizer, (or analyzer).   The benefit involved is
that, especially in ellipsometer/polarimeter etc. systems which
operate in the IR range of wavelengths, it can be difficult to
cause rotation of a linear polarizer, (or analyzer), without
adversely causing deviation of a beam of electromagnetic
radiation caused to pass therethrough, or causing
mis-coordination of multiple elements thereof, (ie. multiple
tipped wire linear polarizer as described in Patent No.
5,946,098).   The present invention allows setting fixed
substantially linear polarizer, and analyzer azimuthal

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orientations, and use the odd bounce optical image rotating element instead to effect different electromagnetic beam azimuthal rotation orientations.

5   Continuing, as mentioned, the present invention finds use in a spectroscopic ellipsometer system basically comprising:

        a source of polychromatic electromagnetic radiation;
        a substantially linear polarizer which is fixed in position
         during data acquisition;
10   a stage for supporting a sample system;
        an analyzer which is fixed in position during data
           acquisition; and
        a multi-element spectroscopic detector system.

15 wherein the substantially linear polarizer and analyzer can be elements which include a narrow elongated slit therein, through which a beam of random polarization state electromagnetic radiation is caused to pass, to the end that it emerges therefrom as a beam of electromagnetic radiation with a linear polarization
20 imposed thereupon.   Further, the substantially linear Polarizer can be a Brewster Angle element in which only a "p" or "s" component of a beam of electromagnetic radiation caused to interact therewith near a "Brewster Angle" Angle-of-Incidence,
25 emerges therefrom in reflection or transmission, respectively; wherein the "p" component indicates a polarization state aligned with a perpendicular to a surface of a Brewster Angle Polarizer and also in the plane of incidence of said beam, and where "s" indicates a polarization components perpendicular to the "p"
30 component and also parallel to said surface of the Brewster Angle Polarizer".   While such spectroscopic ellipsometer system can be operated with a continuously rotating polarizer or analyzer during data collection, the preferred approach is to include at least one compensator somewhere between the polarizer and

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analyzer which is caused to continuously rotate during data acquisition, while the polarizer and analyzer are held essentially fixed.

A basic present invention system then, can be described as comprising a functional combination of a fixed position substantially linear polarizer in combination with an odd bounce optical image rotating system comprising a sequence of an odd number of reflective elements oriented in a manner which causes an entering beam of electromagnetic radiation to reflect from a first thereof onto the second thereof and from the second thereof onto the third thereof etc., such that said odd number of reflections cause a beam of electromagnetic radiation to emerge from the last odd number reflective element which is not significantly deviated or displaced from the locus of the input beam, even when the odd bounce optical image rotating element system is caused to rotate about an axis coincident with the locus of the beam of electromagnetic radiation. Said combination of substantially linear polarizer and odd bounce optical image rotating system serve to provide means for rotating the azimuthal angle of a substantially linearly polarized beam of electromagnetic radiation exiting said substantially linear polarizer without rotating the polarizer. Said combination of substantially linear polarizer and odd bounce optical image rotating system finds application in ellipsometer and polarimeter and the like systems.

A basic present invention method of effecting and changing a polarization state of a beam of electromagnetic radiation comprises the steps of:

a. providing a system for effecting a polarization state change comprising in functional combination:

a fixed position polarizer; and

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an odd bounce optical image rotating system
comprising a sequence of an odd number of
reflective elements oriented in a manner which
causes an entering beam of electromagnetic
radiation to reflect from a first thereof onto the
second thereof and from the second thereof onto the
third thereof etc., such that said odd number of
reflections cause a beam of electromagnetic
radiation to emerge from the last reflective
element thereof which is not significantly deviated
or displaced from the locus of the input beam, even
when the odd bounce optical image rotating element
system is caused to rotate about an axis coincident
with the locus of the beam of electromagnetic
radiation;

b. entering an electromagnetic beam to said polarizer;

c. stepwise or continuously rotating said odd bounce optical
image rotating system about an axis coincident with the locus of
the electromagnetic beam.

Said method of effecting and changing a polarization state of a
beam of electromagnetic radiation preferably involves the odd
bounce optical image rotating system being stepwise rotated about
the axis coincident with the locus of the electromagnetic beam
such that the polarization state of said beam of electromagnetic
radiation is generally affected much as would be the case if the
polarizer were so stepwise rotated.

Where data is to be obtained by directing a resulting beam
into a detector, the odd bounce optical image rotating system can
be caused to continuously rotate during data acquisition,
however, preferred present invention practice is to cause another

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element, (eg. an analyzer or compensator), to be present and
rotate during data acquisition while holding the polarizer and
odd bounce optical image rotating system both motionless between
stepped azimuthal angle changes.

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Continuing, a present invention ellipsometer system
typically comprises at least one means for continuously modifying
a polarization state of a beam of electromagnetic radiation
through a plurality of polarization states during use.   The
Polarizer and/or Analyzer can be caused to rotate as one option
10   and when adopted results in Rotating Analyzer and Rotating
Polarizer based systems.   However, the preferred present
invention provides that the odd bounce optical image rotating
system be positioned between a stationary polarizer and analyzer,
(preferably near the linear polarizer), and be operated as a
15   means for sequentially step-wise modifying a polarization state
of a beam of electromagnetic radiation through a plurality of
polarization states, while a compensator, which is also present
between the stationary polarizer and analyzer, is caused to
continuously rotate, while a beam of electromagnetic radiation
20   caused to pass therethrough.   (Note, this does not exclude the
possibility of providing and rotating more than one compensator).
While the preferred present invention ellipsometer system can
utilize essentially any Compensator, a preferred embodiment of
the present invention provides that the compensator, which is
25   mounted to allow continuous rotation about the locus of a beam of
electromagnetic radiation caused to pass therethrough, be
selected from the group of consisting of:

30   a single element compensator;

a compensator system comprised of at least two per se.
zero-order waveplates (MOA) and (MOB), said per se.
zero-order waveplates (MOA) and (MOB) having their respective

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fast axes rotated to a position offset from zero or ninety degrees with respect to one another, with a nominal value being forty-five degrees;

a compensator system comprised of a combination of at least a first (ZO1) and a second (ZO2) effective zero-order wave plate, said first (ZO1) effective zero-order wave plate being comprised of two multiple order waveplates (MOA1) and (MOB1) which are combined with the fast axes thereof oriented at a nominal ninety degrees to one another, and said second (ZO2) effective zero-order wave plate being comprised of two multiple order waveplates (MOA2) and (MOB2) which are combined with the fast axes thereof oriented at a nominal ninety degrees to one another; the fast axes (FAA2) and (FAB2) of the multiple order waveplates (MOA2) and (MOB2) in said second effective zero-order wave plate (ZO2) being rotated to a position at a nominal forty-five degrees to the fast axes (FAA1) and (FAB1), respectively, of the multiple order waveplates (MOA1) and (MOB1) in said first effective zero-order waveplate (ZO1);

a compensator system comprised of a combination of at least a first (ZO1) and a second (ZO2) effective zero-order wave plate, said first (ZO1) effective zero-order wave plate being comprised of two multiple order waveplates (MOA1) and (MOB1) which are combined with the fast axes thereof oriented at a nominal ninety degrees to one another, and said second (ZO2) effective zero-order wave plate being comprised of two multiple order waveplates (MOA2) and (MOB2) which are combined with the fast axes thereof oriented at a nominal ninety degrees to one another; the fast axes (FAA2) and (FAB2) of the multiple order waveplates (MOA2) and (MOB2) in said second effective zero-order wave plate (ZO2) being rotated to a position away from zero or ninety degrees with

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respect to the fast axes (FAA1) and (FAB1), respectively, of the multiple order waveplates (MOA1) and (MOB1) in said first effective zero-order waveplate (ZO1);

a compensator system comprised of at least one zero-order waveplate, ((MOA) or (MOB)), and at least one effective zero-order waveplate, ((ZO2) or (ZO1) respectively), said effective zero-order wave plate, ((ZO2) or (ZO1)), being comprised of two multiple order waveplates which are combined with the fast axes thereof oriented at a nominal ninety degrees to one another, the fast axes of the multiple order waveplates in said effective zero-order wave plate, ((ZO2) or (ZO1)), being rotated to a position away from zero or ninety degrees with respect to the fast axis of the zero-order waveplate, ((MOA) or (MOB)).

Additional compensator systems, previously disclosed in Patent Application 08/997,311, (now Patent 5,946,098), and CIP's therefrom, which compensators are specifically within the scope of application with the present invention, and can be included in the above identified selection group are:

a compensator system comprised of a first triangular shaped element, which as viewed in side elevation presents with first and second sides which project to the left and right and downward from an upper point, which first triangular shaped element first and second sides have reflective outer surfaces; said retarder system further comprising a second triangular shaped element which as viewed in side elevation presents with first and second sides which project to the left and right and downward from an upper point, said second triangular shaped element being made of material which provides reflective interfaces on first and second sides inside thereof; said second triangular shaped element being

oriented with respect to the first triangular shaped element such that the upper point of said second triangular shaped element is oriented essentially vertically directly above the upper point of said first triangular shaped element; such that in use an input electromagnetic beam of radiation caused to approach one of said first and second sides of said first triangular shaped element along an essentially horizontally oriented locus, is caused to externally reflect from an outer surface thereof and travel along a locus which is essentially upwardly vertically oriented, then enter said second triangular shaped element and essentially totally internally reflect from one of said first and second sides thereof, then proceed along an essentially horizontal locus and essentially totally internally reflect from the other of said first and second sides and proceed along an essentially downward vertically oriented locus, then externally reflect from the other of said first and second sides of said first triangular shaped elements and proceed along an essentially horizontally oriented locus which is undeviated and undisplaced from the essentially horizontally oriented locus of said input beam of essentially horizontally oriented electromagnetic radiation even when said retarder is caused to rotate; with a result being that retardation is entered between orthogonal components of said input electromagnetic beam of radiation;

a compensator system comprised of, as viewed in upright side elevation, first and second orientation adjustable mirrored elements which each have reflective surfaces; said compensator/retarder system further comprising a third element which, as viewed in upright side elevation, presents with first and second sides which project to the left and right and downward from an upper point, said third element being made of material which provides reflective interfaces on first and second sides inside thereof; said third element

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being oriented with respect to said first and second
orientation adjustable mirrored elements such that in use an
input electromagnetic beam of radiation caused to approach
one of said first and second orientation adjustable mirrored

5   elements along an essentially horizontally oriented locus, is
caused to externally reflect therefrom and travel along a
locus which is essentially upwardly vertically oriented, then
enter said third element and essentially totally internally
reflect from one of said first and second sides thereof, then

10   proceed along an essentially horizontal locus and essentially
totally internally reflect from the other of said first and
second sides and proceed along an essentially downward
vertically oriented locus, then reflect from the other of
said first and second orientation adjustable mirrored

15   elements and proceed along an essentially horizontally
oriented propagation direction locus which is essentially
undeviated and undisplaced from the essentially horizontally
oriented propagation direction locus of said input beam of
essentially horizontally oriented electromagnetic radiation

20   even when said compensator/retarder is caused to rotate; with
a result being that retardation is entered between orthogonal
components of said input electromagnetic beam of radiation;

       a compensator system comprised of a parallelogram shaped
25   element which, as viewed in side elevation, has top and
bottom sides parallel to one another, both said top and
bottom sides being oriented essentially horizontally, said
retarder system also having right and left sides parallel to
one another, both said right and left sides being oriented at

30   an angle to horizontal, said retarder being made of a
material with an index of refraction greater than that of a
surrounding ambient; such that in use an input beam of
electromagnetic radiation caused to enter a side of said
retarder selected from the group consisting of: (right and

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left), along an essentially horizontally oriented locus, is caused to diffracted inside said retarder system and follow a locus which causes it to essentially totally internally reflect from internal interfaces of both said top and bottom sides, and emerge from said retarder system from a side selected from the group consisting of (left and right respectively), along an essentially horizontally oriented locus which is undeviated and undisplaced from the essentially horizontally oriented locus of said input beam of essentially horizontally oriented electromagnetic radiation even when said retarder is caused to rotate; with a result being that retardation is entered between orthogonal components of said input electromagnetic beam of radiation;

a compensator system comprised of first and second triangular shaped elements, said first triangular shaped element, as viewed in side elevation, presenting with first and second sides which project to the left and right and downward from an upper point, said first triangular shaped element further comprising a third side which is oriented essentially horizontally and which is continuous with, and present below said first and second sides; and said second triangular shaped element, as viewed in side elevation, presenting with first and second sides which project to the left and right and upward from an upper point, said second triangular shaped element further comprising a third side which is oriented essentially horizontally and which is continuous with, and present above said first and second sides; said first and second triangular shaped elements being positioned so that a rightmost side of one of said first and second triangular shaped elements is in contact with a leftmost side of the other of said first and second triangular shaped elements over at least a portion of the lengths thereof; said first and second triangular shaped elements each being made of material with an index of refraction greater than that of a

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surrounding ambient; such that in use an input beam of electromagnetic radiation caused to enter a side of a triangular shaped element selected from the group consisting of: (first and second), not in contact with said other triangular shape element, is caused to diffracted inside said retarder and follow a locus which causes it to essentially totally internally reflect from internal interfaces of said third sides of each of said first and second triangular shaped elements, and emerge from a side of said triangular shaped element selected from the group consisting of: (second and first), not in contact with said other triangular shape element, along an essentially horizontally oriented locus which is undeviated and undisplaced from the essentially horizontally oriented locus of said input beam of essentially horizontally oriented electromagnetic radiation even when said retarder is caused to rotate; with a result being that retardation is entered between orthogonal components of said input electromagnetic beam of radiation;

a compensator system comprised of a triangular shaped element, which as viewed in side elevation presents with first and second sides which project to the left and right and downward from an upper point, said retarder system further comprising a third side which is oriented essentially horizontally and which is continuous with, and present below said first and second sides; said retarder system being made of a material with an index of refraction greater than that of a surrounding ambient; such that in use a an input beam of electromagnetic radiation caused to enter a side of said retarder system selected from the group consisting of: (first and second), along an essentially horizontally oriented locus, is caused to diffracted inside said retarder system and follow a locus which causes it to essentially totally internally reflect from internal interface of said third

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sides, and emerge from said retarder from a side selected
from the group consisting of (second and first respectively),
along an essentially horizontally oriented locus which is
undeviated and undisplaced from the essentially horizontally
oriented locus of said input beam of essentially horizontally
oriented electromagnetic radiation even when said retarder
system is caused to rotate; with a result being that
retardation is entered between orthogonal components of said
input electromagnetic beam of radiation; and

a compensator system comprised of first and second Berek-type
retarders which each have an optical axes essentially
perpendicular to a surface thereof, each of which first and
second Berek-type retarders has a fast axis, said fast axes
in said first and second Berek-type retarders being oriented
in an orientation selected from the group consisting of:
(parallel to one another and other than parallel to one
another); said first and second Berek-type retarders each
presenting with first and second essentially parallel sides,
and said first and second Berek-type retarders being
oriented, as viewed in side elevation, with first and second
sides of one Berek-type retarder being oriented other than
parallel to first and second sides of the other Berek-type
retarder; such that in use an incident beam of
electromagnetic radiation is caused to impinge upon one of
said first and second Berek-type retarders on one side
thereof, partially transmit therethrough then impinge upon
the second Berek-type retarder, on one side thereof, and
partially transmit therethrough such that a polarized beam of
electromagnetic radiation passing through both of said first
and second Berek-type retarders emerges from the second
thereof in a polarized state with a phase angle between
orthogonal components therein which is different than that in
the incident beam of electromagnetic radiation, and in a

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propagation direction which is essentially undeviated and undisplaced from the incident beam of electromagnetic radiation even when said retarder system is caused to rotate; with a result being that retardation is entered between orthogonal components of said input electromagnetic beam of radiation;

a compensator system comprised of first and second Berek-type retarders which each have an optical axes essentially perpendicular to a surface thereof, each of which first and second Berek-type retarders has a fast axis, said fast axes in said first and second Berek-type retarders being oriented other than parallel to one another; said first and second Berek-type retarders each presenting with first and second essentially parallel sides, and said first and second Berek-type retarders being oriented, as viewed in side elevation, with first and second sides of one Berek-type retarder being oriented other than parallel to first and second sides of the other Berek-type retarder; such that in use an incident beam of electromagnetic radiation is caused to impinge upon one of said first and second Berek-type retarders on one side thereof, partially transmit therethrough then impinge upon the second Berek-type retarder, on one side thereof, and partially transmit therethrough such that a polarized beam of electromagnetic radiation passing through both of said first and second Berek-type retarders emerges from the second thereof in a polarized state with a phase angle between orthogonal components therein which is different than that in the incident beam of electromagnetic radiation, and in a propagation direction which is essentially undeviated and undisplaced from the incident beam of electromagnetic radiation, said spectroscopic ellipsometer/polarimeter system further comprising third and forth Berek-type retarders which each have an optical axes essentially perpendicular to a

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surface thereof, each of which third and forth Berek-type
retarders has a fast axis, said fast axes in said third and
forth Berek-type retarders being oriented other than parallel
to one another, said third and forth Berek-type retarders

5   each presenting with first and second essentially parallel
sides, and said third and forth Berek-type retarders being
oriented, as viewed in side elevation, with first and second
sides of one of said third and forth Berek-type retarders
being oriented other than parallel to first and second sides

10   of said forth Berek-type retarder; such that in use an
incident beam of electromagnetic radiation exiting said
second Berek-type retarder is caused to impinge upon said
third Berek-type retarder on one side thereof, partially
transmit therethrough then impinge upon said forth Berek-type

15   retarder on one side thereof, and partially transmit
therethrough such that a polarized beam of electromagnetic
radiation passing through said first, second, third and forth
Berek-type retarders emerges from the forth thereof in a
polarized state with a phase angle between orthogonal

20   components therein which is different than that in the
incident beam of electromagnetic radiation caused to impinge
upon the first side of said first Berek-type retarder, and in
a direction which is essentially undeviated and undisplaced
from said incident beam of electromagnetic radiation even

25   when said retarder system is caused to rotate; with a result
being that retardation is entered between orthogonal
components of said input electromagnetic beam of radiation;

a compensator system comprised of first, second, third and
forth Berek-type retarders which each have an optical axes

30   essentially perpendicular to a surface thereof, each of which
first and second Berek-type retarders has a fast axis, said
fast axes in said first and second Berek-type retarders being
oriented essentially parallel to one another; said first and

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second Berek-type retarders each presenting with first and second essentially parallel sides, and said first and second Berek-type retarders being oriented, as viewed in side elevation, with first and second sides of one Berek-type retarder being oriented other than parallel to first and second sides of the other Berek-type retarder; such that in use an incident beam of electromagnetic radiation is caused to impinge upon one of said first and second Berek-type retarders on one side thereof, partially transmit therethrough then impinge upon the second Berek-type retarder, on one side thereof, and partially transmit therethrough such that a polarized beam of electromagnetic radiation passing through both of said first and second Berek-type retarders emerges from the second thereof in a polarized state with a phase angle between orthogonal components therein which is different than that in the incident beam of electromagnetic radiation, and in a propagation direction which is essentially undeviated and undisplaced from the incident beam of electromagnetic radiation; each of which third and forth Berek-type retarders has a fast axis, said fast axes in said third and forth Berek-type retarders being oriented essentially parallel to one another but other than parallel to the fast axes of said first and second Berek-type retarders, said third and forth Berek-type retarders each presenting with first and second essentially parallel sides, and said third and forth Berek-type retarders being oriented, as viewed in side elevation, with first and second sides of one of said third and forth Berek-type retarders being oriented other than parallel to first and second sides of said forth Berek-type retarder; such that in use an incident beam of electromagnetic radiation exiting said second Berek-type retarder is caused to impinge upon said third Berek-type retarder on one side thereof, partially transmit therethrough

then impinge upon said forth Berek-type retarder on one side thereof, and partially transmit therethrough such that a polarized beam of electromagnetic radiation passing through said first, second, third and forth Berek-type retarders emerges from the forth thereof in a polarized state with a phase angle between orthogonal components therein which is different than that in the incident beam of electromagnetic radiation caused to impinge upon the first side of said first Berek-type retarder, and in a direction which is essentially undeviated and undisplaced from said incident beam of electromagnetic radiation even when said retarder system is caused to rotate; with a result being that retardation is entered between orthogonal components of said input electromagnetic beam of radiation;

In addition, it is noted that a recent Patent to Aspnes describes application of a Berek-type Retarder which presents with an optical axis which is slightly deviated from a normal to the surface thereof, said Berek-type retarder being oriented so that a beam of electromagnetic radiation approaches along a normal to said surface. while the Berek-type Retarder is caused to rotate about said normal to said surface.

Further, while not required, the present invention benefits from Compensator(s) designed to provide relatively constant, achromatic Polarization State Modification effects over a Spectroscopic range of wavelengths.

The present invention will be better understood by reference to the Detailed Description Section of this Specification, in combination with the Drawings.

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SUMMARY OF THE INVENTION

It is therefore a primary purpose and/or objective of the present invention to disclose a system which finds application in ellipsometer/polarimeter and the like systems, which system rotates the azimuthal angle of a linear polarization state of a beam of electromagnetic radiation in a manner which does not significantly cause deviation of displacement thereof.

It is another purpose and/or objective of the present invention to disclose an odd bounce image rotating system which finds application in ellipsometer/polarimeter and the like systems, which odd bounce image rotating system rotates the azimuthal angle of a linear or partially linear, (substantially linear), polarization state of a beam of electromagnetic radiation in a manner which does not significantly cause deviation of displacement thereof.

It is yet another purpose and/or objective of the present invention to disclose a functional combination of a polarizer and an odd bounce image rotating system, wherein the polarizer provides a fixed position polarization state, and wherein the odd bounce image rotating system receives the polarized electromagnetic beam and sets the azimuthal angle of said polarization state.

It is another purpose and/or objective of the present invention to disclose application methodology of odd bounce image rotating systems in material system investigation systems, (eg. ellipsometer and polarimeter and the like systems).

Other purposes and/or objectives will become clear from a reading of the Specification and Claims.

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Fig. 1 demonstrates an odd bounce image rotating system comprising three (3) reflecting elements.

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Fig. 2 demonstrates an odd bounce odd image rotating system comprising five (5) reflecting elements.

Fig. 3a demonstrates a combination fixed position polarizer and rotatable odd bounce image rotating system.

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Fig. 3b shows that the reflective elements in the rotatable odd bounce image rotating system of Fig. 3a can be pivotally mounted.

Fig. 3c shows an end view of the rotatable odd bounce image rotating system of Fig. 3a is rotatable about the output electromagnetic beam.

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Figs. 3d and 3e are included to demonstrate that a physical half rotation of an odd bounce optical image rotating system (OBIRS), (see Fig. 3d), around output electromagnetic beam (EMO), as viewed in Fig. 3c causes a full rotation of the linear polarization vector (see Fig. 3e).

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25   Fig. 4 demonstrates a rotating compensator ellipsometer system in which an odd bounce image rotating system is present after a fixed position linear polarizer.

Fig. 5 demonstrates a preferred compensator (C) (C') C''), (see

30   Fig. 4), for use in a rotating compensator ellipsometer system for application in the IR range of wavelengths.

Figs. 6a and 6b show a five (5) bounce odd bounce image rotating system (OBIRS), which should be beneficially compared to Fig. 2 to gain insight to how function and physical construction are related.

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DETAILED DESCRIPTION

Turning now to Fig. 1, there is represented a three (3) bounce odd bounce image rotating system (OBIRS) comprising three (3) reflective elements (RE1), (RE2) and (RE3), oriented with respect to one another such that an input beam of electromagnetic radiation (EMI) exits as an output beam of electromagnetic radiation (EMO) without any deviation or displacement being entered into the locus thereof.

Fig. 2 demonstrates a five (5) bounce odd bounce image rotating system (OBIRS) wherein five reflective elements (RE1'), (RE2') (RE3'), (RE4') and (RE5') oriented with respect to one another such an input beam of electromagnetic radiation (EMI) exits as an output beam of electromagnetic radiation (EMO) without any deviation or displacement being entered into the locus thereof. Note generally that the angle of incidence of the (EMI) and (EMO) beams of electromagnetic radiation are nearer normal than is the case in the Fig. 1 three (3) bounce odd bounce image rotating system (OBIRS). This is beneficial in that the closer to normal the angle of incidence, the less aberration effects are entered to the beam. However, it is also to be appreciated that construction of the Fig. 2 system is more difficult than is construction of a Fig. 1 system.

Fig. 3a demonstrates a combination fixed position polarizer (FP) and rotatable odd bounce image rotating system (OBIRS) which in combination provide a means for providing a polarized beam of electromagnetic radiation and for controlling the azimuthal angle of the polarization, without the need to rotate the fixed polarizer (FP).

Fig. 3b demonstrates that the reflective elements (RE1),

(RE2) and (RE3) can be mounted pivotally via pivots (P1), (P2) and (P3) to allow easy alignment, so that the input (EM1) and output (EMO) beams of electromagnetic radiation can be oriented along the same locus, without deviation and displacement effects causing the output (EMO) beam to exit along a different locus than along that input beam (EMI) enters.

Figs. 3d and 3e are included to demonstrate that a physical half rotation of an odd bounce optical image rotating system (OBIRS), (see Fig. 3d), around output electromagnetic beam (EMO), as viewed in Fig. 3c causes a full rotation of the polarization vector (see Fig. 3e).

Fig. 4 demonstrates a rotating compensator ellipsometer system in which an odd bounce image rotating system (OBIRS) is present immediately after a fixed polarizer (FP). Note also the relative orientation of a polychromatic electromagnetic radiation (LB1), optional compensator (C1) sample system (SS), optional compensator (C2), analyzer (A) and detector (DET) in the demonstrative upper reflective portion, (eg. follow electromagnetic beam (LBI) to (LBO). Further shown is a demonstrative transmissive portion comprised of optional compensator (C3), analyzer (A') and detector (DET'), (eg. follow electromagnetic beam (LBI) to (LBO). Preferred present invention practice has it that at least one of the compensators (C1), (C2) and (C3) will be present and caused to rotate during data acquisition and the odd bounce image rotating system (OBIRS) will be stepped to various azimuthal angle positions and set motionless during data acquisition, which the fixed linear polarizer (FP) and analyzer (A) (A') are held stationary. That is, the preferred present invention application is in a rotating compensator ellipsometer system, wherein the combination of the fixed polarizer and the odd bounce image rotating system (OBIRS) provide an effective rotatable polarizer. This is useful where

a polarizer, (such as tipped wire grid plate polarizers used in the IR wavelength range), is difficult to rotate while maintaining alignment of the components therein and while avoiding deviation and displacement affects between input (EMI) and output (EMO) electromagnetic beams.

Fig. 5 demonstrates a preferred compensator (C) (C') C'') for use in a rotating compensator ellipsometer system for application in the IR range of wavelengths. The compensator system comprises, as shown in upright side elevation, first (OS1) and second (OS2) orientation adjustable mirrored elements which each have reflective surfaces. Note the adjustability enabling pivot (PP1) (PP2) mountings. Said compensator system further comprises a third element (TE) which, as viewed in upright side elevation presents with first (IS1) and second (IS2) sides which project to the left and right and downward from an upper point (UP2), said third element (TE) being made of material which provides reflective interfaces on first and second sides inside thereof. Said third element (TE) is oriented with respect to the first (OS1) and second (OS2) orientation adjustable elements such that in use an input electromagnetic beam of radiation (LB) caused to approach one of said first (OS1) and second (OS2) orientation adjustable mirrored elements along an essentially horizontally oriented locus, is caused to externally reflect therefrom upwardly vertically oriented, (see beam (R1)) then enter said third element (TE) and essentially totally internally reflect from one of said first and second sides thereof, then proceed along an essentially horizontal locus (see beam (R2)), and essentially totally internally reflect from the other of said first (OS1) and second (OS2) sides and proceed along an essentially downward vertically oriented locus, (see beam (R3)), then reflect from the other of said first (OS1) and second (OS2) adjustable mirrored elements and proceed along an essentially horizontally oriented (LB') propagation direction locus which is

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essentially undeviated and undisplaced from the essentially
horizontally oriented locus of said input beam of electromagnetic
radiation even when said compensator is caused to rotate about
the locus of the beam of electromagnetic radiation, with the
result being that retardation is entered between orthogonal
components of said input electromagnetic beam of radiation. Also
shown are third element lower side (IS3), with indication that it
can be shaped as shown by (IS3'), and retain functionality.

Figs. 6a and 6b show a five (5) bounce odd bounce image
rotating system (OBIRS), which should be beneficially compared to
Fig. 2 to gain insight to how function and physical construction
are related. Again, Fig. 2 shows five reflective elements
(RE1'), (RE2') (RE3'), (RE4') and (RE5') oriented with respect to
one another such an input beam of electromagnetic radiation (EMI)
exits as an output beam of electromagnetic radiation (EMO)
without any deviation or displacement being entered into the
locus thereof. Fig. 6a identifies an input beam of
electromagnetic radiation (EMI) exits from a five (5) bounce odd
bounce image rotating system (OBIRS), as an output beam of
electromagnetic radiation (EMO), (note that (EMI) and (EMO) are
realistically shown as beams with a non-zero radius). The Fig.
6a positioning of the reflective elements (RE1'), (RE2') (RE3'),
(RE4') and (RE5') lead to the reflections shown in Fig. 2.
Fig. 6b further demonstrates physical construction of the Fig. 6a
five (5) bounce odd bounce image rotating system (OBIRS).

Finally, it is to be understood that while preferred
embodiments provide for application of a linear polarizer, the
present invention can be used with a substantially linearly
polarizing polarizer, or a polarizer which provides partially
linearly polarization. In the Claims the term "polarizer"
should then be interpreted broadly to mean preferably a linear
polarizer, but including polarizers which provide partially

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linearly polarization.

Having hereby disclosed the subject matter of the present
invention, it should be obvious that many modifications,
5   substitutions, and variations of the present invention are
possible in view of the teachings. It is therefore to be
understood that the invention may be practiced other than as
specifically described, and should be limited in its breadth and
scope only by the Claims.

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